

VII. THEODORE ROOSEVELT NATIONAL PARK

...along the Little Missouri, it would be strange indeed, if any one found it otherwise than attractive in the bright, sharp fall weather...under the cloudless blue sky the air was fresh and cool...at night the stars shone with extraordinary brilliancy.

Theodore Roosevelt
January 20, 1915

A. DESCRIPTION

Theodore Roosevelt National Park (THRO) consists of three separate units (North, Elkhorn, and South) in western North Dakota and encompasses natural, scenic, and historical resources. The Little Missouri River winds through the North and South Units and forms the eastern boundary of the Elkhorn Unit.

Efforts to establish a park in the North Dakota badlands were initiated as early as 1917, although it was not until 1934 that the federal government began to acquire submarginal (for agriculture and grazing) lands for Roosevelt Regional Park; these lands were later designated as a Recreational Demonstration Area administered by the National Park Service. Theodore Roosevelt Memorial NP was officially established in 1947 as a memorial to honor Theodore Roosevelt, and the park name was eventually changed to Theodore Roosevelt NP in 1978.

THRO is managed to protect and interpret the badlands ecosystems surrounding the Little Missouri River and the cultural resources resulting from human habitation of the area (THRO 1994). Maintenance and restoration of the natural environment, including physical and biological resources and ecosystem processes, is a critical management objective. Natural processes will be permitted to continue with a minimum of human disturbance. An additional objective is the protection and interpretation of human history, with emphasis on President Theodore Roosevelt. Maintaining natural areas and wilderness characteristics is potentially difficult due to development on and uses of adjacent private, state, and federal lands.

The three units of THRO comprise 26,578 ha. Although annual park visitation has been as high as 1 million, it is currently about 500,000, with 72% of visitation during June through August (THRO 1992). Approximately 42% of the park has been designated as wilderness.

1. Geology and Soils

The park falls within the Missouri Plateau and North Dakota Badlands sections of the Great Plains physiographic province. The badlands begin near the headwaters of the Little Missouri River in northeastern Wyoming and extend for 220 km, becoming deeply dissected eastward in the region of the park, and terminating where the river enters the Garrison Reservoir. The badlands consist of a complex of dissected canyons and coulees which have been eroded by the river and other streams over time. This has resulted in a variety of landforms, including buttes and ridges that support

grassland vegetation. Rolling hills that extend eastward from the badlands also support grasslands, while drainages and riparian areas support a variety of shrubs, trees, and forbs.

A large portion of THRO consists of rugged badlands, comprised of Paleocene deposits that have been eroding since the Pliocene. Sandstone, siltstone, and clays are interspersed with beds of lignite in a complex array of stratigraphic patterns and colors that are an important visual resource for visitors. Some of the lignite strata have burned over time, baking the overlying clays into a bright pink to purple "scoria" that is a distinctive part of the landscape. Some areas of the badlands contain fossils created from Paleocene forests and swamps; fossils are revealed through continued erosion of surrounding geological strata.

Soils in the park developed from excessively drained, medium-textured, and calcareous parent material. Soil texture generally ranges from loams to clay loams. Saturated soils in this region tend to be highly erodible and can result in considerable slumping from the shoulder slope and backslope of existing landforms.

The Natural Resources Conservation Service completed a soil survey of THRO in 1994. Soils in the park are predominantly classified as torriorhents formed under prairie in a hot, dry climate. The major soils of the park are in the Badlands-Bainville Association. Some soils in THRO grade into haploborolls with deep soil profiles mainly confined to range sites on lower prairie slopes (e.g., the Morton soil series), but are generally quite localized.

The Havre soil series originates in alluvial bottoms, while the Patent soil series is derived from recently-deposited sediments on colluvial fans. Both of these series are fine-textured and often have a claypan and salt buildup. The more restricted Banks series occurs on the bottomlands along the Little Missouri River in recent alluvial deposits.

The Flasher series is comprised of coarse sandy soils on steep side slopes and crests of sandstone-capped ridges. The coarse gravel Parshall series is found on the high terrace remnants of the ancestral Little Missouri River such as the Petrified Forest Plateau. Both of these soils support prairie vegetation on gentle slopes. The widespread "badlands" component of the park is not classified as a soil by the Natural Resource Conservation Service although at least some vegetation is found on most slopes.

2. Climate

THRO has a continental climate characterized by cold winters and hot summers. Three major air masses influence climate in this area at various times of the year: 1) maritime pacific air from the west which has crossed the Rocky Mountains; 2) maritime tropical air from the south; and 3) continental polar air originating from Canada, Alaska and the arctic (ECOS Management Criteria, Inc. 1987). Each of the three air masses produces characteristic meteorological conditions. Maritime pacific air produces cool, stable, conditions in summer, and cold, dry conditions in winter. Maritime tropical air is warmer and more humid, is the major source of moisture, and is more

prevalent during the summer months. Continental polar air is the cause of the extremely cold weather during the winter months; during the summer it results in cool, dry conditions.

Annual precipitation is 38 cm, most of which falls in the spring and summer, primarily during thunderstorms. Mean precipitation during June, the wettest month, is 8.8 cm. Average annual snowfall is 78 cm, with snow falling between October and May. During July and August, average maximum temperature is 30° C, and average minimum temperature is 16° C. Temperatures can reach as low as -18° C from October through April, with a record low of -44° C in 1950.

The prevailing wind direction in the vicinity of THRO is from the west to northwest, with a secondary maximum from the southeast (Bison Engineering/Research 1985). Wind rose data from the north and south units of THRO indicate that winds are frequently in excess of 15 mph. There are no well-defined air basins in this area. However, the complex valley-ridge terrain causes distinct local channeling of air flows, particularly during low wind speed conditions (U.S. Department of the Interior 1982). This effect is particularly pronounced during cold, stable atmospheric conditions characterized by temperature inversions.

3. Biota

Vegetation in THRO includes 574 species of vascular plants, most of which are adapted to a semiarid climate. At least 109 different species of bryophytes and 208 species of lichens have been identified in THRO as well. Grazing by domestic cattle and cultivation that occurred prior to creation of the park have altered the natural vegetation to some extent, and there are at least 57 species of exotic plants in the park.

Upland grasslands are found on deep, well-drained soils on moderate to shallow slopes dominated by wheat grasses (*Agropyron* spp.), needle grasses (*Stipa* spp.), blue grama (*Bouteloua gracilis*), smooth brome (*Bromus inermis*), little bluestem (*Andropogon scoparius*), fringed sage (*Artemisia frigida*), and sedges (*Carex* spp.). Dry breaks are found on areas of highly eroded silts or scoria surfaces and are dominated by sparse stands of little bluestem, blue grama, sideoats grama (*Bouteloua curtipendula*), red threeawn (*Aristida purpurea* var. *longiseta*), and scattered shrubs such as juniper (*Juniperus* spp.), saltbush (*Atriplex* spp.), and greasewood (*Sarcobatus vermiculatus*). Wooded draws are found in concavities in the landscape where soil moisture tends to be higher and where surface and subsurface water movement is greater; wooded draws are dominated by Rocky Mountain juniper (*Juniperus scopulorum*), green ash (*Fraxinus pennsylvanica*), and chokecherry (*Prunus virginiana*). The understory is dominated by snowberry (*Symphoricarpos* spp.), skunkbush sumac (*Rhus trilobata*) and a variety of graminoids, mosses, and lichens. Sagebrush and grassland bottoms are formed by alluvial deposits from the Little Missouri River and its larger tributaries, and comprise the higher floodplains and river terraces. They are dominated by silver sagebrush (*Artemisia cana*), western wheatgrass species, needle and thread (*Stipa comata*), and blue grama

species, with fringed sage species, prairie rose species, and snowberry as additional woody components. Floodplain forests are found on the lowest terrace along perennial streams. They are dominated by plains cottonwood (*Populus deltoides*), with subdominants Rocky Mountain juniper, green ash, chokecherry, wildrye (*Elymus* spp.), wheat grasses, and sedges. Grasses and forbs may replace the woody understory in some locations. Riparian vegetation is associated with a narrow band between floodplain forest and a perennial stream. The dominant vegetation is normally various willow species (*Salix* spp.), with wildrye, prairie cordgrass (*Spartina pectinata*), and rushes in the understory. An alternative approach to classifying vegetation at THRO uses physiographic/vegetation classes based on a combination of landform and gross structure of the vegetation (THRO 1994) (Table VII-1).

Over 250 species of vertebrate fauna are found in THRO. Large mammals include white-tailed deer (*Odocoileus virginianus*), mule deer (*O. hemionus*), bison (*Bison bison*), elk (*Cervus elaphus*), pronghorn (*Antilocapra americana*), and a few bighorn sheep (*Ovis canadensis*). Mammalian predators include coyote (*Canis latrans*), bobcat (*Lynx rufus*), red fox (*Vulpes vulpes*), and weasel (*Mustela* spp.). There are many species of small mammals including small rodents, striped skunk (*Mephitis mephitis*), beaver (*Castor canadensis*), porcupine (*Erethizon dorsatum*), and prairie dogs (*Cynomys* spp.).

Many raptors nest in the park including golden eagle (*Aquila chrysaetos*), prairie falcon (*Falco mexicanus*), and kestrel (*Falco sparverius*). Additional large nesting birds include turkey vulture (*Cathartes aura*), great horned owl (*Bubo virginianus*), screech owl (*Otus kennecotti*), burrowing owl (*Athene cunicularia*), red-tailed hawk (*Buteo jamaicensis*), rough-legged hawk (*Buteo lagopus*), northern harrier (*Circus cyaneus*), and wild turkey (*Meleagris gallopardo*). Many species of passerine birds are also found in the park.

There is little information on the distribution and abundance of reptile and amphibian species in the park. Reptiles that are likely residents include western plains garter snake (*Thamnophis radix*), plains hog-nosed snake (*Heterodon nasicus*), yellow-bellied racer (*Coluber constrictor*), bullsnake (*Pituophis melanoleucus sayi*), prairie rattlesnake (*Crotalus viridis*), and short-horned lizard (*Phrynosoma douglassii*). Amphibians that may be residents are the Great Plains toad (*Bufo cognatus*) and Rocky Mountain toad (*B. woodhousii*).

4. Aquatic Resources

The major surface water resource in THRO is the Little Missouri River. The river flows through 14 km of the South Unit and 21 km of the North Unit, and forms the eastern boundary of the Elkhorn

Table VII-1. Vegetation classes in THRO.	
Class	Description
Breaks	Areas mostly devoid of vegetation
Cottonwood forests	Forests along perennial streams dominated by plains cottonwood
Wooded draws	Dominated by either green ash or quaking aspen (<i>Populus tremuloides</i>)
Upland grasslands	Level to rolling grasslands found on the plains above the Little Missouri River valley
Old river terraces	Level grassland 50 to 150 m above the Little Missouri River
Grassland flats	Large, flat grassy alluvial deposits found 30 to 60 meters above the Little Missouri River
Bottom grasslands	Large, flat grassy alluvial deposits found on the higher floodplain of the Little Missouri River and its larger tributaries
Toe slopes	Gradually sloping lands formed by slumping and alluvial deposition; covered with grass, shrubs, and trees,
Rolling grasslands	Level to rolling grasslands in the North Unit found on the glaciated plains above the Little Missouri River
Achenbach hills	Hills found 200 meters above the Little Missouri River in the North Unit which are covered by grass and shrubs
Ridge and ravine	Lands highly dissected by drainages and covered by grasses, shrubs, and trees
Scoria hills	Lands influenced by scoria which have differential weathering, producing rugged and varied topography with a variety of grasses and shrubs
Sagebrush bottoms	Floodplains dominated by silver sagebrush along with substantial grass cover
Prairie dog towns	Lands formerly or currently influenced by prairie dogs (<i>Cynomys</i> spp.), with sparse vegetation near the center
Juniper woodlands	Cool, moist sites generally found on north-facing slopes dominated by Rocky Mountain juniper

Unit. The river is wild and free-flowing. Most other streams within the park are intermittent with little or no flow during the summer.

The Little Missouri River generally has high turbidity, high mineral content, wide fluctuations in flow rate, and a shifting bottom of various textures. It contains aquatic communities that are relatively species-poor, although it does support populations of several gamefish, including northern pike (*Esox lucius*), walleye (*Stizostedion vitreum*), sauger (*S. canadense*) and channel catfish

(*Ictalurus punctatus*). There are approximately 25 species of fish in the river that are found within the boundary of the park (THRO 1994). The silvery minnow (*Hybognathus nuchalis*) and the plains minnow (*Hybognathus placitus*) represent about 80% of the number of fish in the river as a whole. There is almost no information on invertebrate species in the river and its tributaries.

There are 10 developed springs and 15 flowing wells in the park. Limited data have been collected on flow rate and chemical characteristics of these hydrological resources. Many other springs and seeps are not inventoried or developed. There is little information on groundwater characteristics and variation in the water table. The U.S. Geological Survey is currently developing a profile of groundwater quantities for the park. There is concern that energy development adjacent to the park could affect water quality in the park through contamination of groundwater aquifers and streams by well blowouts, spills, or leakage of petroleum or saltwater.

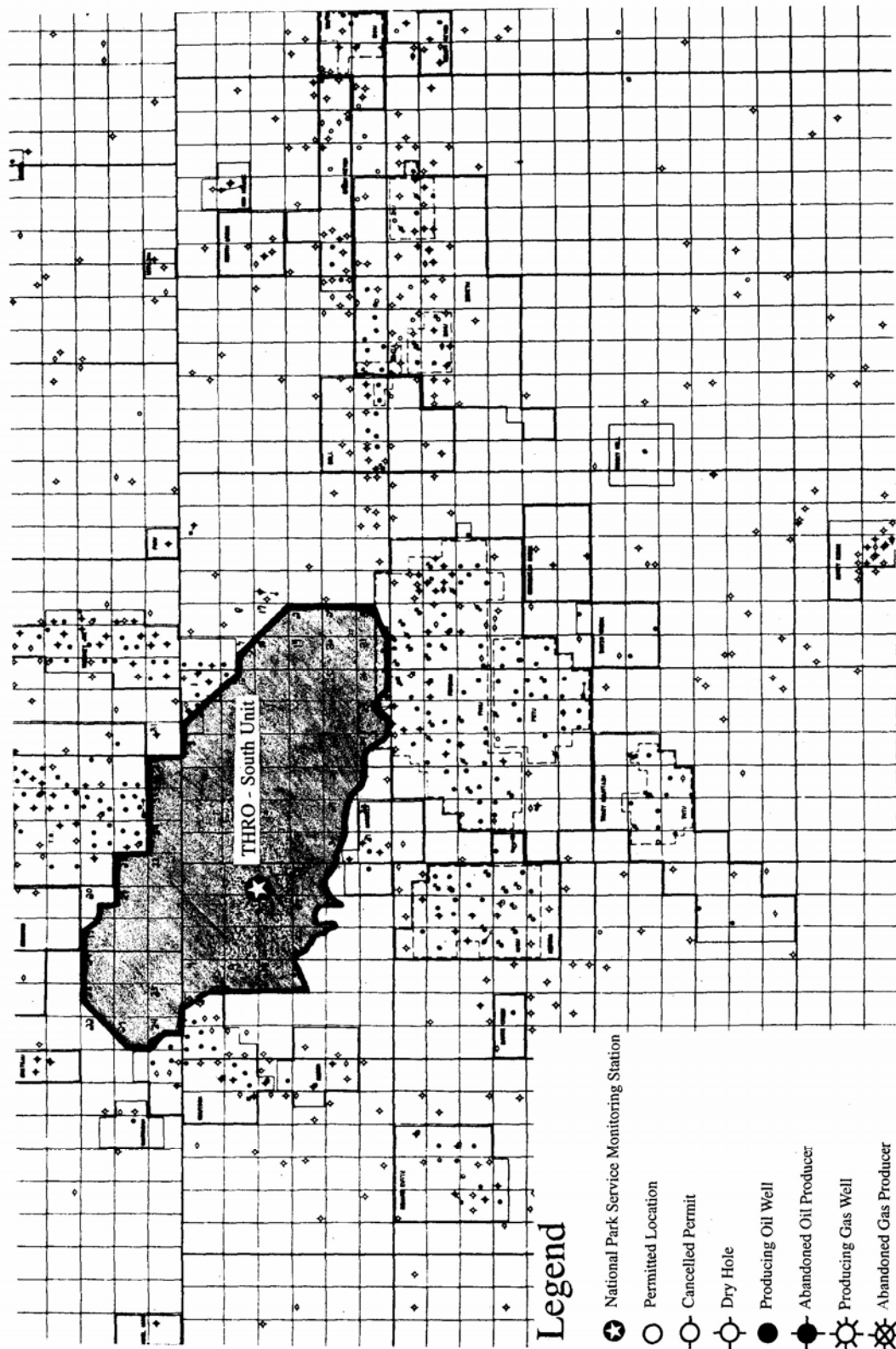
B. EMISSIONS

Air quality within the park has generally been regarded as good, although there are concerns about current and future energy development adjacent to the park. The human population is sparse near THRO and there are no large metropolitan areas. The major sources of pollution are associated with oil and gas production as well as coal-fired electricity generation, which adds S and particulates to the atmosphere. There are approximately 20 major point sources of gaseous sulfur pollution in the vicinity of the park (Roger Andrascik, pers. comm.).

The greatest air quality impact to the park comes from oil and gas wells in the vicinity. Over 1,500 producing oil and gas wells have been drilled in Billings and McKenzie Counties, the two counties in which the park is located (Figures VII-1 and VII-2). There are 630 new wells proposed near the park in the next 10 years. Large areas around the park have been proposed to be managed for high mineral potential so it is likely that the levels of oil and gas production from this region will increase or at least remain at current levels.

An inventory of SO₂ emissions near THRO was conducted by the North Dakota State Department of Health (NDSDH) for the National Park Service. The inventory was conducted in 1981 and 1982 and included only point sources within approximately 50 km of any of the three units of the park. Of the total SO₂ emissions for the area (33,500 tons per year), 22,000 tons per year were attributed to oil and gas wells while the remaining 11,500 tons per year were emitted by larger point sources (North Dakota State Department of Health 1983).

In 1987, there were 16 sources within 250 km of THRO that emitted more than 250 tons per year of SO₂ (Weber and White 1990). The largest source is the Coal Creek power plant which emits 50,000 tons per year of SO₂. This power plant, along with the next four largest emitters, are located to the east of THRO.



Legend

National Park Service Monitoring Station

Permitted Location

Cancelled Permit

Dry Hole

Producing Oil Well

Abandoned Oil Producer

Producing Gas Well

Abandoned Gas Producer

THRO is unique among Class I air quality areas of the Rocky Mountains and the northern Great Plains because hydrogen sulfide (H_2S) emissions in its vicinity are a significant concern. H_2S is a highly toxic gas that is formed by the decomposition of organic matter containing S. It is found in mines, wells, sewers, cesspools, natural gas, volcanic gas and in some spring waters. It is a colorless, flammable gas with a density greater than that of air. Air pollution by H_2S is not a widespread problem but rather is typically localized near sources such as oil and gas wells, kraft paper mills, sewage treatment plants, petroleum refineries and coke ovens.

The oil fields of western North Dakota were developed primarily for the production of crude oil but many have also been developed with gas-gathering networks by which natural gas, which is produced in association with crude oil, can be transported to gas processing plants (Weber and White 1990). In areas not equipped with a gas-gathering pipeline system, the gas produced from a well is used to operate lease equipment and the excess is flared. The content of H_2S in raw gas can range from 0 to as high as 30% (NDSDH 1983).

The flaring of the gas converts the H_2S to SO_2 . Reports of the efficiencies of conversion vary greatly, from 30% to 100%. H_2S is also emitted by fugitive releases of raw gas from leaky valves, pipe connections or tank hatches. Therefore, the amount of H_2S and SO_2 emitted from any particular well depends upon many factors including production rate, percentage of H_2S in the raw gas, the presence or absence of gas-gathering lines, flaring efficiency, and amount of raw gas fugitive releases. It should be noted that altering the flaring efficiency can vary the amount of either H_2S or SO_2 emitted but can never reduce the total amount of sulfur that is emitted.

From 1982 to 1984, the NPS reviewed seven PSD permit applications for energy conversion and natural gas sweetening facilities within a 200-km radius of the park. Emissions modeling predicted that some Class I air quality increments within the park would be exceeded, although NAAQS at the source areas would not be violated. However, because it could not be demonstrated that vegetation or visibility would be significantly affected by the sources, the Department of the Interior issued a certification of no adverse impact on the park, and the state granted construction permits for six of the plants. Proposals for coal-fired power plants in eastern Wyoming and a gas sweetening facility (Enron Gas Processing Company) in Rawson, ND, northwest of the park are a source of ongoing concern with respect to future air quality in the park (THRO 1992, 1994).

Installation of a new well is not subject to the PSD regulatory process. However, the additive effect of many of these small sources may be greater than that of a single, larger source. These smaller sources contribute to regional pollution problems and should not be considered insignificant because they are not categorized as "major". In addition, a small source such as an oil well has the potential to cause high concentrations of pollutants in its immediate vicinity. Under certain meteorological conditions the plume of pollutants from a small source has the potential to impact sensitive plant species in the park. Therefore, it is important to consider small sources such as oil and gas wells as contributors to both regional and localized air quality problems.

In the last decade, a decrease in production has occurred in the oil and gas industry in North Dakota due to depressed market conditions. This decrease in production, along with the inclusion of gas gathering lines, has significantly decreased the emissions of SO₂ and NO_x. In addition, several large point sources of SO₂ have ceased operation. The decrease in emissions has presumably reduced the impact on the park as well as decreased North Dakota's contribution to regional haze. Future exploration and development during improved economic market conditions still may threaten air quality.

Historically, fires, and therefore smoke, have been a part of the Great Plains ecosystem. Fires are generally not considered to be a significant long term source of pollutants but they can result in episodes of degraded visibility and high particulate matter concentrations.

North Dakota has State Ambient Air Quality Standards that are more restrictive than NAAQS, including H₂S standards and a 1-hour standard for SO₂. The North Dakota state 1-hour SO₂ standard is 273 ppbv. The 24-hour SO₂ standard is 99 ppbv and the annual standard is 23 ppbv.

Hydrogen sulfide standards were initially set at 32 ppbv maximum half-hour concentration not to be exceeded more than twice in any five consecutive days and 54 ppbv maximum half-hour concentration not to be exceeded more than twice per year. In 1987, a single H₂S half-hour standard of 50 ppbv was promulgated. The standard is set primarily to control odors caused by H₂S and is not designed to protect human health or natural resources (Weber and White 1990).

North Dakota has adopted air quality rules that are specific to the oil and gas industry (Weber and White 1990). These rules are found in Chapter 33-15-20 "Control of Emissions from Oil and Gas Production Facilities" of the North Dakota Air Pollution Control Rules. The rules require the owner or operator of a well installed after July 1, 1987, or any well existing prior to this date that would emit 10 tons per year or more of any sulfur compound, to register the well with the NDSDH. Although not specifically a permitting process, the NDSDH can use the registration information to determine whether the oil production facility should comply with state air quality rules, including applicable ambient air quality standards and PSD increments. As of 1990, approximately 700 wells had been registered with the NDSDH. The rules also require owner/operators of oil and gas production facilities to flare waste gas that contains H₂S or treat it in an equally effective manner prior to releasing it to the atmosphere. If a flare system is used, the flare must be equipped with an automatic ignitor or a continuous burning pilot.

A local emission source at THRO is a vehicle pull-out near the Painted Canyon area, which is a popular rest stop for diesel trucks. Drivers may stop for several hours or overnight with their engines running. There is some concern from park resource managers regarding potential impacts on air quality in the Painted Canyon area. Generalized emission rates for idling diesel trucks are estimated to be 50 g/hour of NO_x, 92 g/hour of CO and 12 g/hour of VOCs. The negative effects of CO would be primarily on human health, particularly in the early morning hours when trucks have been running all night and atmospheric mixing is low. NO_x and VOCs are also a concern because they are the

precursors of ozone and therefore would be of greatest concern during the summer months. Further monitoring would be necessary to determine the effect of trucks in this area.

C. MONITORING AND RESEARCH ACTIVITIES

1. Air Quality/Deposition

a. Wet Deposition

The concentrations of SO_4^{2-} , NO_3^- , and NH_4^+ in precipitation at THRO are moderate (Table VII-2). Sulfate and NH_4^+ concentrations are actually somewhat higher than at the two wet deposition monitoring stations in Rocky Mountain National Park, and the NO_3^- concentrations at THRO tend to be intermediate between the two Rocky Mountain NP sites. The volume of precipitation at THRO is low, however, generally in the range of 25 to 45 cm annually. As a consequence, wet deposition of S and N at the park is low. Wet S deposition is generally in the range of 1.0 to 1.4 kg/ha/yr, and wet N deposition is 1.0 to 2.0 kg/ha/yr, with somewhat more than half generally as NH_4^+ (Table VII-3).

Table VII-2. Wetfall chemistry at the NADP/NTN site at THRO. Units are in $\mu\text{eq/L}$, except precipitation (cm) and H^+ .										
Year	Precip	H^+	SO_4^{2-}	NH_4^+	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-
1995	48.3	5.1	16.7	21.6	15	9.4	2.6	2.5	0.7	1.7
1994	44.2	8.4	20.1	18.9	16.4	11.1	3.1	2.3	0.7	1.8
1993	46.2	4.6	17.3	12.6	12.1	6.9	2.1	4.8	0.5	1.8
1992	31.2	6	18.4	15.6	13.3	9.1	2.5	3	0.4	1.9
1991	35.8	5.7	16.8	15.8	14.6	9.5	2.5	2.2	0.5	1.9
1990	30.8	5.3	23.9	20.7	14.2	11.5	3.8	2.7	0.7	2.5
1989	35.4	2.7	17.9	19.8	13.7	9.3	2.6	2.5	0.5	2.2
1988	22.8	6.3	21.1	12.9	13.4	11.6	3	5.3	0.7	2.6
1987	5	2.4	17	5.5	10.6	11.9	3.8	6.9	0.7	2.2
1986	53.2	3.9	18.3	11.5	9.5	9.8	3	2.2	0.5	1.5
1985	32.4	6.6	23.9	13.3	12.9	14.2	4.5	2.9	0.8	2.2
1984	22.7	5.7	37	14.9	17.2	29.9	12.1	8.3	2.2	5.2
1983	26.2	6.5	23.3	12.9	15.5	15.5	5	3.6	0.9	2.8
1982	54.3	6.1	20.6	9.9	12.2	14.6	5.6	2.7	1.6	2.2
1981	26.4	4.1	31.8	19.5	17.5	20.4	9.1	5.4	1	3.4
Average	34.3	5.3	21.6	15.0	13.9	13.0	4.4	3.8	0.8	2.4

Table VII-3. Wet deposition (kg/ha/yr) of sulfur and nitrogen at the NADP/NTN site at THRO.				
Date	Sulfur	NO ₃ -N	NH ₄ -N	Total Inorganic N
1995	1.3	1.0	1.5	2.5
1994	1.4	1.0	1.2	2.2
1993	1.3	0.8	0.8	1.6
1992	0.9	0.6	0.7	1.3
1991	1.0	0.7	0.8	1.5
1990	1.2	0.6	0.9	1.5
1989	1.0	0.7	1.0	1.7
1988	0.8	0.4	0.4	0.8
1987	0.1	0.1	0.0	0.1
1986	1.6	0.7	0.9	1.6
1985	1.2	0.6	0.6	1.2
1984	1.3	0.5	0.5	1.0
1983	1.0	0.6	0.5	1.0
1982	1.8	0.9	0.8	1.7
1981	1.3	0.6	0.7	1.4
Average	1.2	0.7	0.8	1.4

b. Occult/Dry Deposition

There are no dry deposition data available in the vicinity of THRO.

c. Gaseous Monitoring

Monitoring by the NDSDH indicates that air quality is generally good in the vicinity of THRO. Currently, gases are monitored only at the North Unit. Monitoring equipment at the South Unit was removed because ambient levels of SO₂ and H₂S rarely exceeded the minimum detection levels of the equipment. In general, the complex topography of the park makes it difficult to monitor gaseous pollutants; for example, with respect to sulfur, H₂S tends to settle while SO₂ tends to remain aloft. Currently, ozone, SO₂, and H₂S are the only gaseous pollutants monitored in THRO (Table II-5). Historical gaseous monitoring activities are summarized in Table VII-4.

Ozone has been monitored at THRO since 1983. Table VII-5 is a summary of maximum 1-hour ozone concentrations at THRO. The highest ozone concentration measured at the park was 80 ppbv (1983). Ozone concentrations are similar to those found at GLAC, BADL, and YELL and significantly lower than those at ROMO. Perhaps more importantly, with respect to damage to sensitive plant species, the mean daytime 7-hour ozone concentration during the growing season ranged between 37 and 51 ppbv during this time period. The SUM60 exposure index is another indicator that can be important in assessing ozone exposures of plant species. This index is the

Table VII-4. Gaseous monitoring data collected at the North (N) and South (S) Units of THRO. (Source: NDSDH 1985-1995)			
	SO ₂	Ozone	H ₂ S
1980	S,N		
1981	S,N		
1982	S,N		
1983	S,N	N	
1984	S,N	N	
1985	S,N	N	
1986	S,N	N	
1987	S,N	N	S,N
1988	S,N	N	S,N
1989	S,N	N	S,N
1990	S,N	N	S,N
1991	N	N	N
1992	N	N	N
1993	N	N	N
1994	N	N	N
1995	N	N	N
1996	N	N	N

sum of all hourly ozone concentrations equaling or exceeding 60 ppbv. The SUM60 index at THRO ranged between 121 and 12,488. For comparison, National Parks in highly polluted areas (e.g., southern California) can have SUM60 exposure indexes exceeding 100,000 ppbv-hour (Joseph and Flores 1993).

The primary air quality concern at THRO is sulfur exposure (in the forms of SO₂ and H₂S). Table VII-6 is a summary of these two pollutants as measured at the North and South units. The state 1-hour SO₂ standard is 273 ppbv. The highest concentration was about 18% of the standard.

“Pristine” air is expected to contain about 0.19 ppbv SO₂ (Urone 1976), and some grasses have been found to have biomass reductions when grown in atmospheres of 17 to 29 ppbv throughout the growing season (Crittendon and Read 1979).

The state H₂S standard is 50 ppbv (1-hour average). The highest concentration measured at the North Unit in 1995 was 66% of the standard. Although the H₂S standard has not been exceeded it should be noted that these standards were set in order to control odors. THRO vegetation may be potentially impacted at pollutant concentrations lower than the standards.

The current and previous monitoring stations for SO₂ and H₂S are located at the headquarters in each unit. These locations are relatively distant from most of the oil and gas fields (see Figures II-1 and VII-2). Several oil and gas wells are located close to the park border but relatively far from the monitoring station, thus the potential exists for high sulfur concentrations immediately within the

Table VII-5. Summary of THRO ozone concentrations (ppbv) from NPS monitoring sites (Joseph and Flores 1993, NPS unpublished monitoring data).

	1983 ^a	1984	1985	1986 ^b	1987 ^c	1988 ^d	1989 ^d	1990 ^e	1991 ^d	1992	1993	1994
1-hour maximum	80	68	61	62	64	78	73	70	70	63	64	79
Average daily mean	28	29	31	32	32	42 ¹	39	35	36	33	31	34
Growing season 7-hour mean	51	40	39	38	37	50	46	42	44	40	37	42
SUM60 exposure index (ppbv-hour)	4,496	2,766	121	365	186	12,488	10,983	3,099	3,038	791	685	1,123

^a July, August, and September data not collected

^b October, November, and December data not collected

^c Data collected April through October only

^d Data collected April through September only

^e Data collected May through September only

Table VII-6. SO₂ and H₂S concentrations at THRO from 1987 to 1995. The state 1-hour SO₂ standard is 273 ppbv. The state H₂S standard is 50 ppbv (1-hour average) and one exceedence per year is allowed. (Source: North Dakota State Department of Health 1985-1995)

	Year	SO ₂		H ₂ S	
		Maximum 1-hour value (ppbv)	Average value (ppbv)	Maximum 1-hour value (ppbv)	Average value (ppbv)
North Unit	1989	35.0	1.3	10.0	1.0
	1990	21.0	1.2	10.0	1.0
	1991	40.0	1.2	32.0	1.0
	1992	20.0	1.2	9.0	1.0
	1993	33.0	1.2	30.0	1.1
	1994	49.0	1.3	29.0	1.1
	1995	23.0	1.2	33.0	1.1
South Unit	1987			4.0	1.0
	1988			9.0	1.0
	1989			10.0	1.0
	1990			1.0	1.0

park boundary to remain undetected by the monitoring equipment. H₂S is not a regional pollutant like SO₂. High concentrations of H₂S tend to be found only in localized areas near the source while at distant monitoring sites no detectable levels are registered. A H₂S monitoring study of an oil field near the North Unit registered H₂S concentrations as high as 13,000 ppbv with equipment placed 0.4 km from the nearest well (Bicknell 1984). Clearly, H₂S emissions from these sources have the potential to impact sensitive plant species and perhaps wildlife at THRO. (The “rotten egg” smell of H₂S was detected during September 1996 adjacent to the park boundary suggesting that levels were relatively high [Peterson and Brace, personal observation]).

Concerns such as these prompted NPS to request that NDSDH monitor SO₂ and H₂S in the South Unit of the park close to the nearby Whiskey Joe oil field. This oil field appears as the large cluster of wells immediately adjacent and to the northeast of the South Unit in Figure VII-2. Because a suitable site was not found in the South Unit due to lack of a power source, poor winter accessibility and visibility concerns by the public, the site was established within the oil field (approximately 2 miles from the park). Monitoring began in July 1995 and was terminated in December 1997. Wind speed and direction were also measured.

Data from this special purpose monitoring site are presented in Table VII-7. The maximum SO₂ levels at this monitoring site were moderate and were sometimes higher and sometimes lower than those measured at the North Unit. For both years for which data are available, SO₂ levels were above the minimum detectable value of the instrument (2 ppbv) approximately 20% of the time (compared with about 10% of the time for the North Unit). This was not unexpected because SO₂ is

Table VII-7. SO ₂ and H ₂ S concentrations (ppbv) from the special purpose monitoring site in the Whiskey Joe oil field near the South Unit of THRO.					
Sampling Period	Maximum 1-hour	2nd Highest 1-hour	Maximum 24-hour	2nd Highest 24-hour	Hourly Arithmetic Average
SO ₂					
1995 Jul-Dec	28	26	9	7	1.7
1996 Jan-Dec	26	25	7	6	1.5
H ₂ S					
1995 Jul-Dec	192	187	45	35	5.2
1996 Jan-Dec	300	295	54	49	11.4

dispersed widely in the atmosphere. Hydrogen sulfide concentrations were consistently higher than at the North Unit and this was also not unexpected because the monitor was located inside of the oil field. In 1995, a recorded value of 192 at the Whiskey Joe site almost exceeded the state 1-hour standard of 200 ppbv and during 1996 it exceeded the standard 18 times. During both years, the Whiskey Joe site recorded the highest 24-hour concentrations and the highest hourly arithmetic average of all the NDSDH sites.

Background levels for H₂S for clean air are estimated to be around 0.2 ppbv (Smith 1990). Monitoring data for a number of pollutants, including H₂S, indicate that the air quality of the North Unit is generally more degraded than that of the South Unit (Bilderback 1990). However, this special purpose monitoring site near the South Unit clearly indicates that air quality can be heavily impacted in the immediate vicinity of oil and gas wells. This information, coupled with the fact that there are large numbers of oil and gas wells in the vicinity of all three units of the park indicate that these sources are having a measurable impact on air quality, especially near the boundaries of the park (Figures VII-1 and VII-2). Although it is unclear to what degree the resources of THRO are being impacted by current concentrations, air quality has been altered by local SO₂ and H₂S emissions.

Since June of 1980, park staff have collected data on incidents of smoke and H₂S odor, as observed from within park boundaries. These data include wind speed, wind direction, time of observation, observation point, and apparent source if known. Incidences of visibility impairment by smoke are also reported. The results are on file at park headquarters in Medora.

2. Water Quality

Water quality data are available from 76 locations in and around THRO (Figure VII-3). Sampling site locations were situated along the Little Missouri River and many of its tributaries (Figure VII-4). Measured pH values were around 8.0 at all monitoring sites except one, which had a very low value of 3.1 (Figure VII-5a). The low pH site, at the Frank Mine, also had an extremely high specific conductance (2560 µS/cm). This site is apparently impacted by acid mine drainage. None

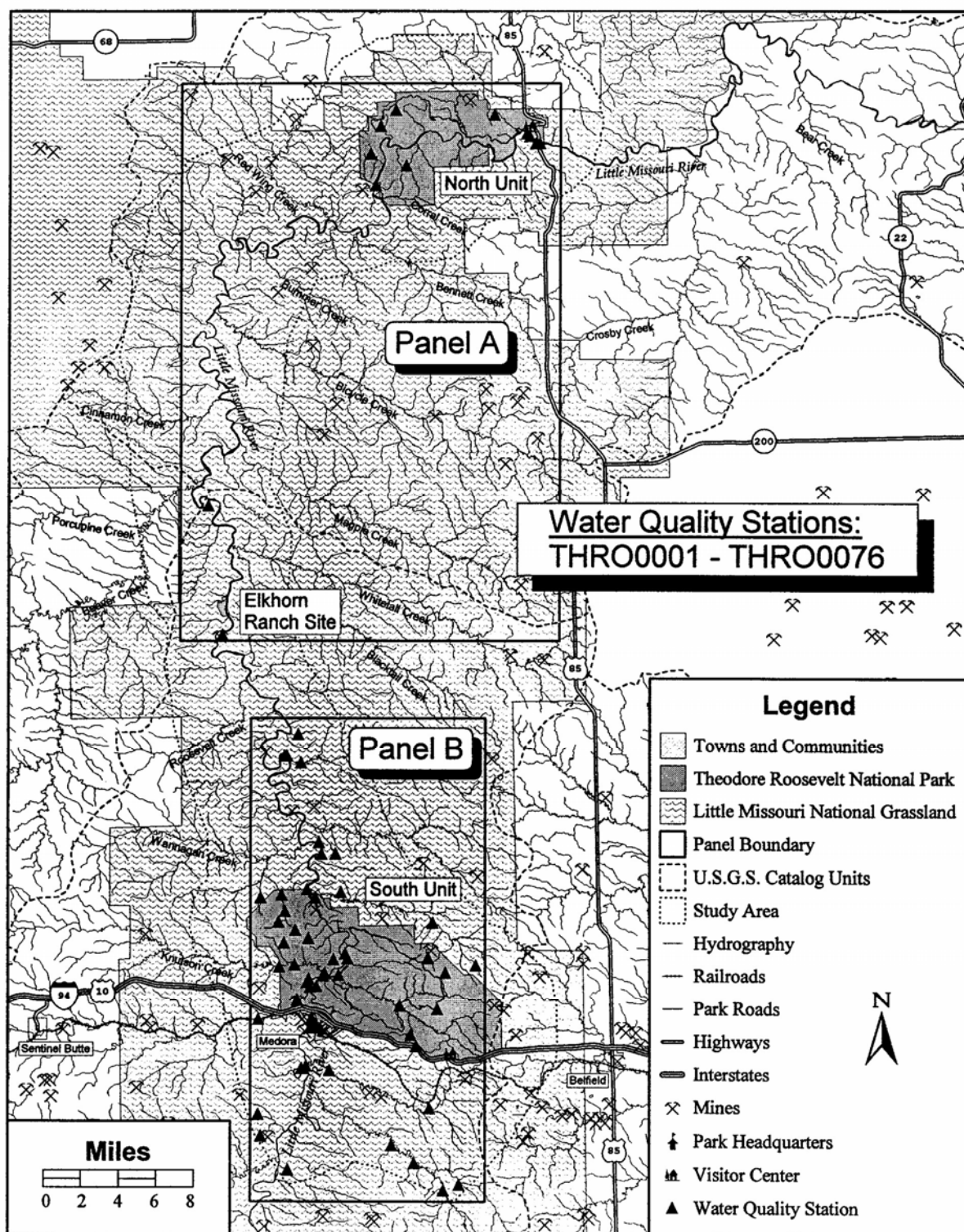


Figure VII-3. Water quality monitoring locations in THRO.

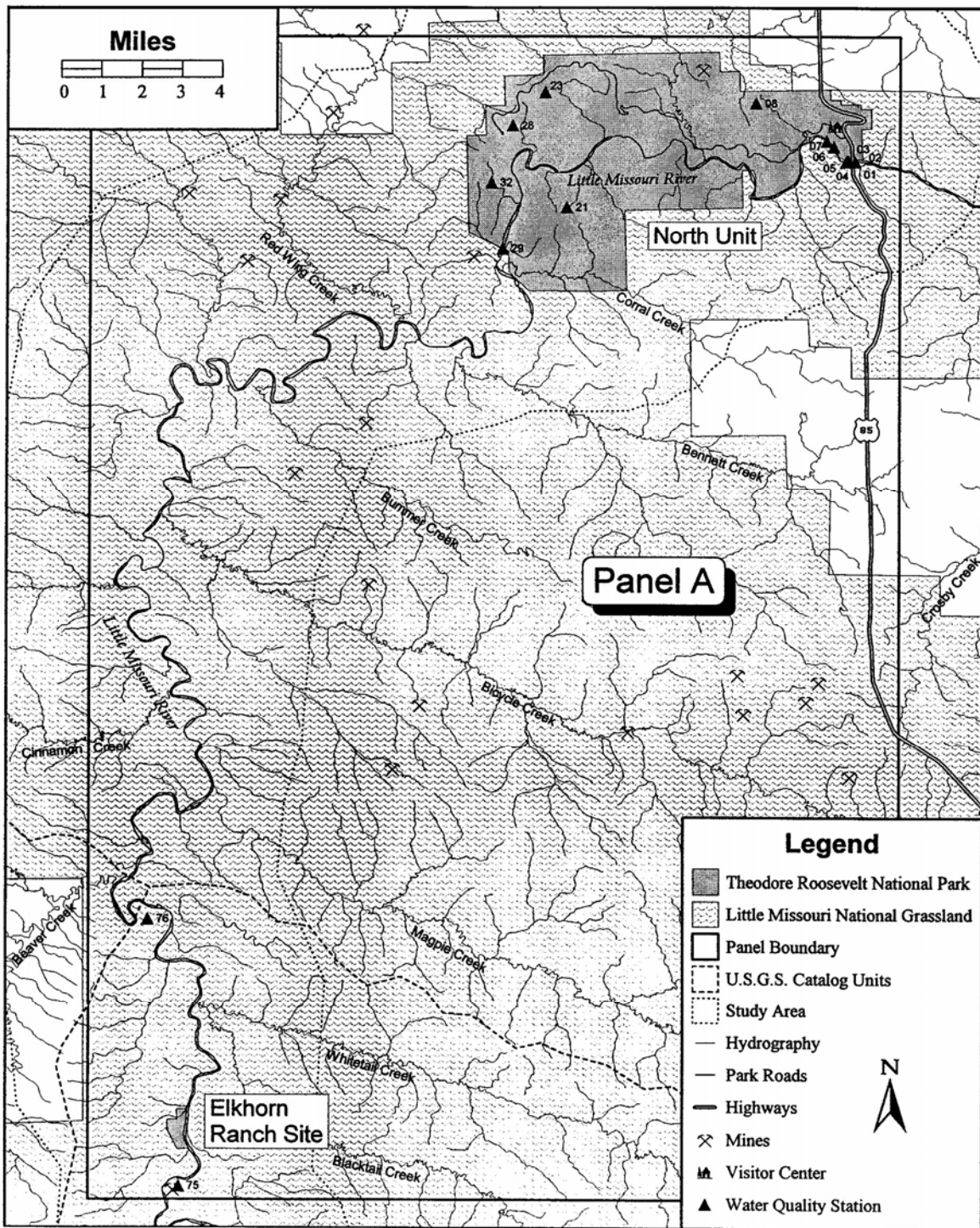


Figure VII-4. Water quality monitoring site identification numbers in the North Unit (Panel A) and the South Unit (Panel B).

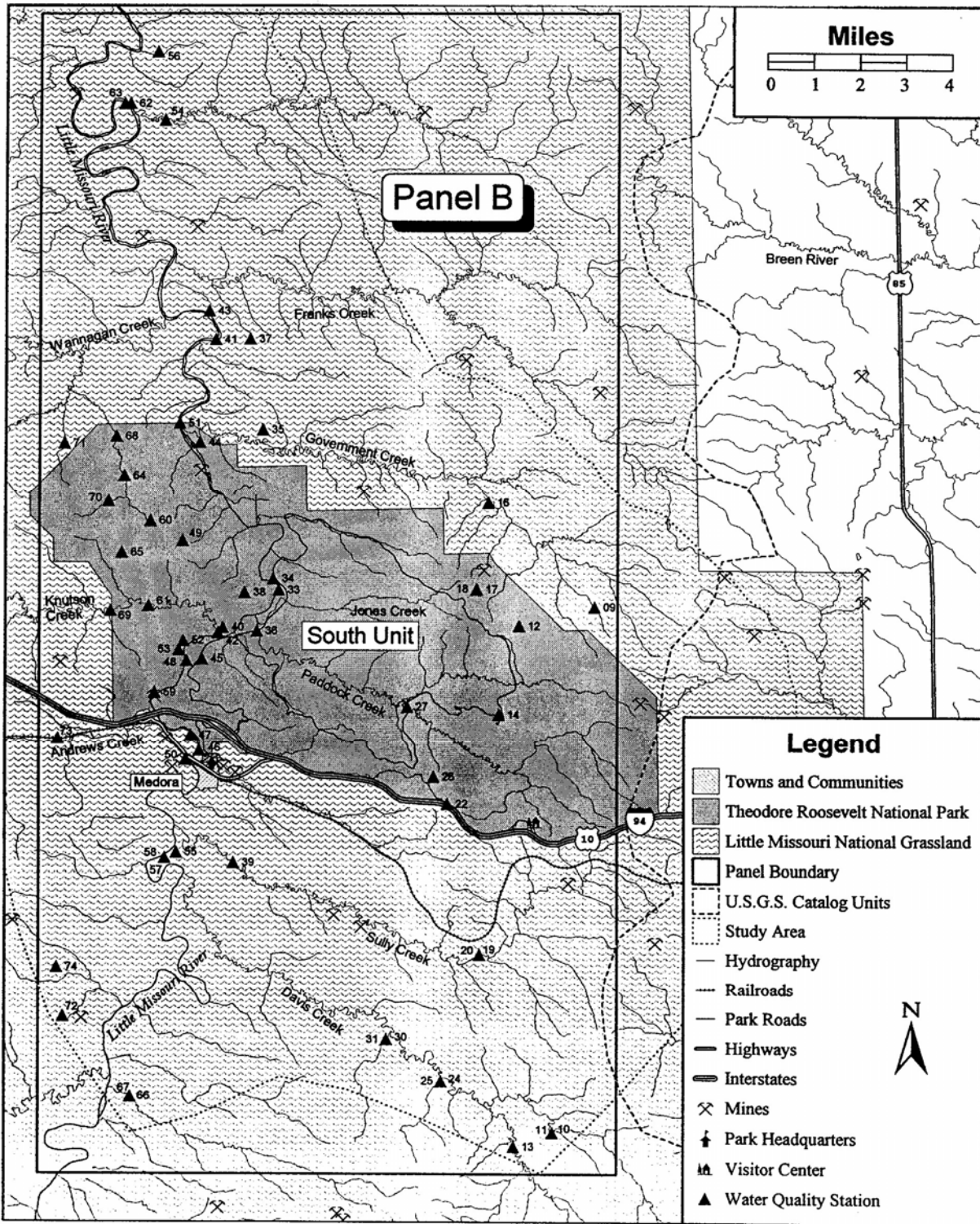


Figure VII-4. Continued.

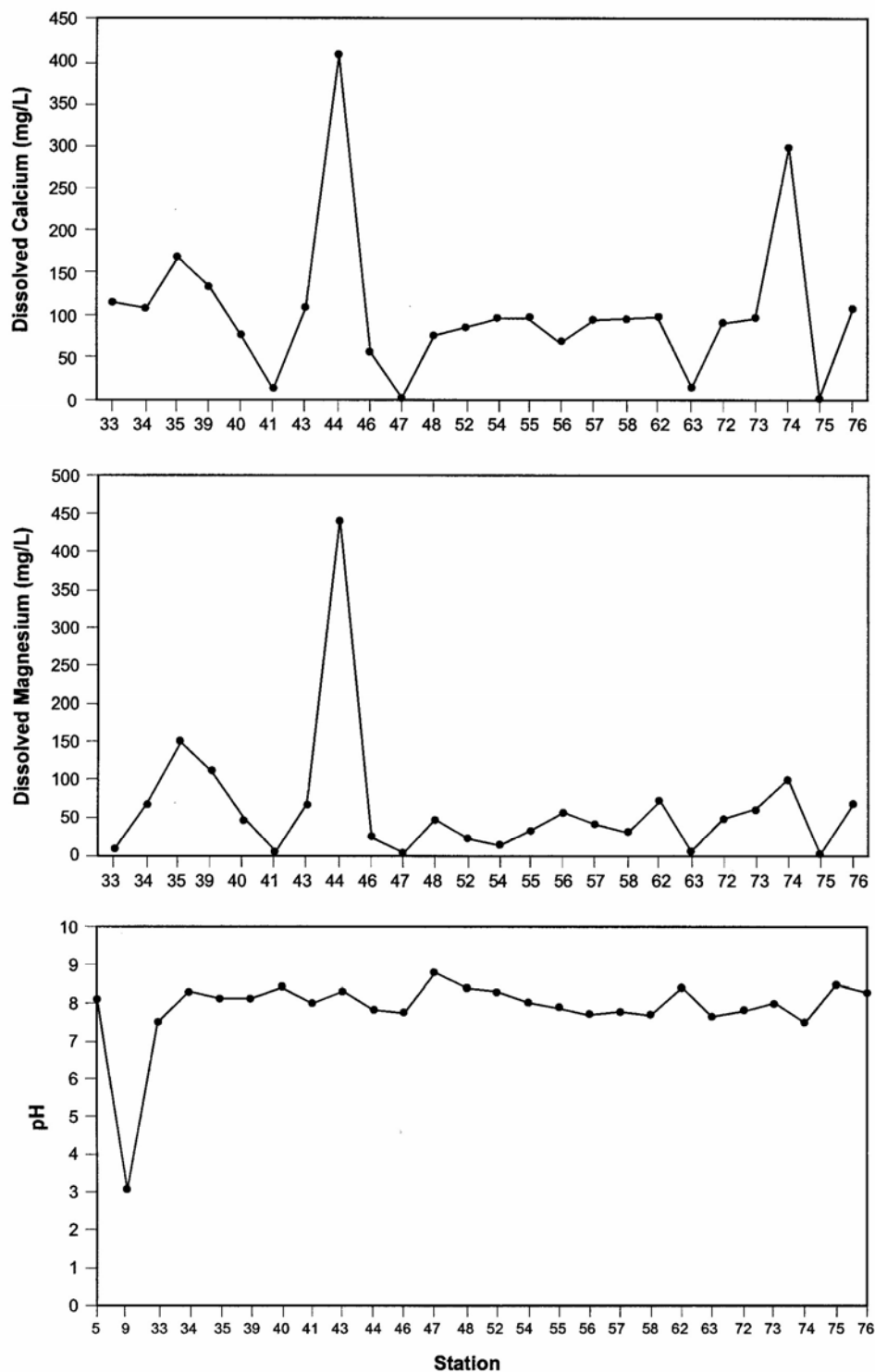


Figure VII-5. Measured Ca^{2+} , Mg^{2+} , and pH values of water quality monitoring sites for which data are available. Station numbers correspond to site locations shown on the preceding figure. For stations having more than one data point, mean values are shown.

of the data at any of the sites reflected sensitivity to acid deposition. There were two sites with moderate concentrations of base cations ($\text{Ca}^{2+} + \text{Mg}^{2+}$ in the range of 250 to 300 $\mu\text{eq/L}$); all other sites had base cation concentrations at least twice as high as these (Figures VII-5b, VII-5c). Existing water quality data for THRO do not suggest sensitivity to potential acidification from acidic deposition. These data are in agreement with expectations based on the physical setting and geology of the park. Aquatic effects from acidic deposition are not currently an important issue in this park.

3. Terrestrial

There have been a number of studies done on the lichens and bryophytes of THRO in relation to air pollution effects (Bilderback 1987, Egan 1984, Gough et al. 1985, Wetmore 1983). There have also been a few studies on vascular vegetation (Gough et al. 1985, Bilderback 1990). None of the studies could conclusively demonstrate that the terrestrial resources of THRO were being significantly impacted by air pollution. However, they do provide valuable baseline information on the status of the terrestrial resources of THRO.

In 1983 a study by Wetmore (1983) established a lichen flora and provided information on distribution. An extensive collection found 208 species, including numerous rare boreal lichens and many significant range extensions. There was no indication that the air quality in THRO was affecting the lichens, because the floristic analysis shows a diverse flora without distribution void. In addition, chemical analyses were performed on seven lichen species: *Parmelia chlorochroa*, *P. flaventior*, *P. mexicana*, *P. soledica*, *P. sulcata*, *Rhizoplaca chrysoleuca*, and *R. melanophthalma*. The S levels in the lichens ranged from 480 to 1426 ppm (based on dry weight of thallus). Levels may be as low as 200-300 ppm in the arctic (clean area) and as high as 4,300-5,200 ppm in polluted areas. The levels found in THRO are considered to be close to background. Although different lichen species typically accumulate sulfur at different rates, there was no discernible difference between these seven species. There was also no discernible pattern of lichen S content distribution in the park. The multi-element analyses also showed no abnormal levels for the other elements that were analyzed, namely Ca, Mg, Na, K, P, Fe, Mn, Al, Cu, Zn, Cd, Cr, Ni, Pb, and B.

A report entitled "The ecological role of lichens in Theodore Roosevelt National Park, North Dakota" detailed the various roles that lichens play in the ecosystems found in THRO (Egan 1984). The report was prepared in response to the proposed construction of a gas processing plant approximately 25 kilometers from the North Unit. The report estimates the biomass of different classes of lichens and attempts to quantify their contribution to ecological processes such as the food chain, nitrogen fixation, soil formation and soil stabilization. With an assumption that either 5% or 10% of the sensitive lichens would die with the increased air pollution, the effects upon the ecological roles of lichens was judged to be insignificant. However, these findings were greatly limited by a lack of knowledge of the sensitivities of most lichen species to air pollution. There were

Table VII-8. Summary of mean sulfur concentrations of the moss *Abietinella abietina* from the North and South Units of THRO and the nearby Lone Butte oil field. (Source: Bilderback 1987)

Location	Total Sulfur (mg/g)
Lone Butte oil field	1078 ± 90
North Unit site 1	775 ± 34
North Unit site 2	806 ± 88
North Unit site 3	833 ± 61
South Unit site 1	706 ± 64
South Unit site 2	744 ± 97
South Unit site 3	668 ± 75
South Unit site 4	768 ± 65
South Unit site 5	767 ± 73

many other limitations on the study as well and more information is needed before a realistic assessment of the effect of increased air pollution upon lichen populations can be made.

Few data have been collected on trace metal deposition in the park. There was, however, a baseline elemental analysis study done on bryophytes (Bilderback 1987). Total S as well as 15 other elements were analyzed in the common moss *Abietinella abietina* from several locations

within the park as well as from a nearby oil field. *Abietinella* was chosen because it was easily identifiable, abundant in THRO and exhibited visible damage in the Lone Butte oilfield. The S levels for the moss from the nearby oil field were significantly higher than those from the park. Levels of other elements were not found to be elevated and there was no discernible pattern in the S concentrations in moss samples taken within the park (Table VII-8). There was also no discernible pattern in the elemental analyses which included P, K, Ca, Mg, Al, Fe, Na, Mn, and other metals. These findings suggest that there is no significant accumulation of these elements in this species in the park that can be traced to a local source, however, it should be noted that little is known about the accumulation of sulfur and other metals by *A. abietina*. Different species vary widely in their accumulation efficiency, and *A. abietina* may or may not be an efficient accumulator.

Vascular plants in THRO have also been sampled and analyzed for sulfur. A study was completed by the USGS on the baseline elemental-composition of selected plants and soils in THRO (Gough et al. 1985). Samples of green ash leaves, western wheatgrass leaves and culms, big sagebrush stems and leaves, the lichen *Parmelia sulcata*, and soils were collected in the park to estimate the biogeochemical variability of the area. The study found no instances of phytotoxic or zootoxic conditions in the plant and soil materials sampled, except for possibly high levels of zinc in the lichen *Parmelia sulcata*. Concentrations of most elements were found to be uniform throughout both the North and South Units of the park. The study established baseline values for many elements and made recommendations for further study.

Bilderback (1990) sampled five plant species at numerous locations in THRO during 1987: big sagebrush, silver sagebrush, western wheat grass, Rocky Mountain juniper, and skunkbush sumac. The sampled vegetation was compared with that from two control sites (40 km south of the South Unit and 8.5 km west of the South Unit) which were chosen because of minimal oil and gas development in their vicinity. The sampled vegetation from the South Unit did not exhibit elevated levels of S. Mean S content of western wheatgrass in the South Unit ranged from 1.1 to 1.7 mg/g

which was not significantly different ($p < 0.05$) from the control sites. Visible symptoms of damage were observed on Rocky Mountain juniper and skunkbush sumac in an oil field near the North Unit in the same study. The stem tips of juniper were yellow or brown, and the leaves of sumac displayed interveinal yellowing (Bilderback 1990).

In the North Unit, some elevated S levels were found but it was not determined whether these levels were due to variation in soil chemistry or deposition of pollutants. Mean S content of western wheatgrass in the North Unit ranged from 1.2 to 2.2 mg/g, whereas control site values for western wheatgrass ranged from 1.1 to 1.4 mg/g. Total S content at four of the sites in the North Unit were not significantly higher than those at the control sites ($p > 0.05$), although two of the sites were higher ($p < 0.05$). Gough et al. (1985) also detected similar elevated levels of S in western wheatgrass for a similar location. Rocky mountain juniper and big sagebrush did not exhibit S contents that were higher than the control site ($p > 0.05$). Silver sagebrush at two sites in the North Unit had S contents significantly higher than that at the South Unit ($p < 0.05$).

D. AIR QUALITY RELATED VALUES

In 1977, the park prepared its first documentation of air quality related values, including historical air quality and important vistas. In 1980, the park prepared a list of integral vistas which included 24 separate sites.

1. Aquatic

There are no air pollution threats to aquatic resources in THRO. This is primarily a consequence of the high buffering capacity of soils in and around the park and consequent high concentrations of base cations and ANC in surface waters.

2. Terrestrial

The principal air pollution threat to terrestrial resources in THRO is S pollution in the form of SO_2 and H_2S . Although ozone pollution is presently not a major concern, the potential for synergistic effects from SO_2 and ozone on vegetation has been documented (Reinert et al. 1969, Tingey and Reinert 1975). Decreases in growth and yield of various crop species were somewhat greater than additive at concentrations of 50 ppbv of each pollutant throughout the growing season, but the differences were not always significant. Greater than additive effects were demonstrated for quaking aspen (*Populus tremuloides*) (Karnosky 1976). Exposure of eastern white pine (*Pinus strobus*) to either gas alone produced 3-4% chlorotic mottle and premature needle drop but was found to increase to 16% when both gases were present at the same doses (100 ppbv, 8 hours/day, 5 days/week for 4-8 weeks) (Treshow and Anderson 1989). Because ambient concentrations of both pollutants in THRO appear to be currently below the threshold doses for sensitive species (especially SO_2), there is no urgent need for concern about synergistic effects. However, if future

monitoring indicates higher pollutant levels than are currently experienced in THRO, synergistic effects should be taken into consideration.

Bioindicators are those species for which pollutant sensitivity has been documented and for which extensive data exist on their dose-response to pollutants and on symptomatology. In some cases, bioindicators can be important indicators of exposure of a pollutant at a site where air quality monitoring data are not available. Ozone and SO₂ are the most extensively studied pollutants regarding impacts on vegetation. Much of this work has been conducted on species native to the northeastern and southwestern United States and very little work has been conducted on species of the Rocky Mountain and northern Great Plains regions.

Vascular plant species of THRO for which there is reference information include western wheatgrass, Rocky Mountain juniper, and skunkbush sumac. However, the use of western wheatgrass as a sensitive receptor may be limited due to its sensitivity to grazing pressures and its annual growth cycle. Rocky Mountain juniper has persistent vegetation, is not subject to grazing pressures, is common in western North Dakota and therefore is a good candidate for bioindicator. Skunkbush sumac is deciduous but warrants further investigation as a bioindicator as well.

Of the hardwood species present at THRO, quaking aspen is the most sensitive to both SO₂ and ozone. Aspen grows at various locations in riparian ecosystems in the park. Numerous studies have documented the sensitivity of this species to ozone under field and experimental conditions (Wang et al. 1986, Karnosky et al. 1992, Coleman et al. 1996), although there is considerable variability in sensitivity among different genotypes (Berrang et al. 1986). Diagnostic ozone symptomatology for aspen includes chlorosis, stippling, necrotic spotting, and leaf margin burn. Symptoms generally vary seasonally, with stippling being most prominent in the spring and black, bifacial (both leaf surfaces) necrosis appearing in late summer (J.P. Bennett, pers. comm.). Great care must be taken in distinguishing ozone symptoms from various pathogens and insect herbivores commonly found on this species. Paper birch (*Betula papyrifera*) is also sensitive to both SO₂ and O₃, although its symptomatology is not as clear as that of aspen, and it is not as common in THRO. Black cottonwood (*P. balsamifera* subsp. *trichocarpa*), which has symptoms similar to those of aspen, is another potential bioindicator for ozone (Woo 1996). However, it is generally regarded as less sensitive to ozone than aspen (Table VII-9). Neither of these hardwood species has the clarity of ozone symptomatology found in conifers such as ponderosa pine (*Pinus ponderosa*) which is too rare in THRO to make it a viable species for monitoring.

An inventory of vascular plants found in THRO was compiled in 1988 and is available in the NPFlora database. Table VII-9 summarizes vascular plant species of THRO with known sensitivity to ozone, SO₂, and NO_x. This table is based on a variety of sources from the published literature and other information. It should be noted that the various sources used a wide range of field and experimental approaches to determine pollutant pathology, and that sensitivity ratings are general estimates based on published information and our expert opinion. While it will not be possible for

park staff to collect data on all the species indicated in Table VII-9, the list can be used by park managers to indicate potentially sensitive species. Of the many plant species in THRO, it is likely that there are many other species that those in the table which have high sensitivity to air pollution, but we currently have no information about them.

Table VII-9. Plant species of THRO with known sensitivities to SO ₂ , ozone, and NO _x . L = low, M = medium, H = high, none = unknown. (Sources: Esserlieu and Olson 1986, Bunin 1990, Blett et al. 1993, National Park Service 1994, Electric Power Research Institute 1995, Binkley et al. 1996, Brace and Peterson 1996)			
Species	SO ₂ Sensitivity	O ₃ Sensitivity	NO _x Sensitivity
<i>Acer negundo</i>	M	M	
<i>Achillea millefolium</i>		L	
<i>Agoseris glauca</i>	M		
<i>Agropyron smithii</i>	M		
<i>Amaranthus retroflexus</i>	M		
<i>Ambrosia psilostachya</i>		L	
<i>Amelanchier alnifolia</i>	H	M	
<i>Arctostaphylos UVa-ursi</i>	L	L	
<i>Artemisia cana</i>	L		
<i>Artemisia ludoviciana</i>	M		
<i>Artemisia tridentata</i>	M	L	
<i>Betula occidentalis</i>	M		
<i>Betula papyrifera</i>	H	H	
<i>Bouteloua gracilis</i>	L		
<i>Bromus tectorum</i>		M	
<i>Calochortus nuttallii</i>		L	
<i>Chenopodium fremontii</i>		L	
<i>Cirsium arvense</i>		L	
<i>Cirsium undulatum</i>	M		
<i>Clematis ligusticifolia</i>	M		
<i>Collomia linearis</i>		L	
<i>Convolvulus arvensis</i>	H		
<i>Cornus stolonifera</i>	M	L	
<i>Corylus cornuta</i>	H	L	
<i>Descurainia pinnata</i>		L	
<i>Festuca octoflora</i>		L	
<i>Fragaria virginiana</i>		H	
<i>Hackelia floribunda</i>	L		
<i>Hedysarum boreale</i>		M	
<i>Helianthus annuus</i>	H	L	
<i>Hymenoxys richardsonii</i>	L		
<i>Juniperus communis</i>	L		
Table 9. Continued.			
Species	SO ₂ Sensitivity	O ₃ Sensitivity	NO _x Sensitivity
<i>Juniperus scopulorum</i>	L		
<i>Medicago sativa</i>		M	

<i>Oryzopsis hymenoides</i>	M		
<i>Pinus ponderosa</i>	M	H	H
<i>Poa pratensis</i>		L	
<i>Polygonum douglasii</i>		L	
<i>Populus tremuloides</i>	H	H	
<i>Potentilla fruticosa</i>		L	
<i>Prunus virginiana</i>	M	H	
<i>Rhus aromatica</i>	H		
<i>Rosa woodsii</i>	M	L	
<i>Rubus idaeus</i>	H		
<i>Rumex crispus</i>		L	
<i>Taraxacum officinale</i>		L	
<i>Toxicodendron radicans</i>	L	L	
<i>Tragopogon dubius</i>	M		
<i>Trifolium pratense</i>	L		
<i>Trifolium repens</i>		H	
<i>Vicia americana</i>		L	
<i>Viola adunca</i>		L	

Table VII-10 summarizes lichen species of THRO with known sensitivity to ozone and SO₂. As in Table VII-9, this table is based on a variety of sources from the published literature and other information. It should be noted that diagnostic symptoms of air pollutant injury to lichens are difficult to identify, and that some species have reduced productivity or even mortality without exhibiting visible symptoms (Nash and Wirth 1988). One of the best sources of background information and guidelines for addressing the use of lichens as sensitive receptors of air pollution is Stolte et al. (1993).

Bryophytes are also quite sensitive to SO₂ exposure; for example, in western Europe most bryophytes have been eliminated from habitats exposed to 170 ppbv SO₂ during the growing season (Gilbert 1968, 1969).

Table VII-10. Lichen and bryophyte species of THRO with known sensitivities to SO₂ and ozone. L = low, M = medium, H = high, none = unknown. (Sources: Peterson et al. 1993, National Park Service 1994, Electric Power Research Institute 1995, Binkley et al. 1996)

Species	SO ₂ Sensitivity	Ozone Sensitivity
<i>Aspicilia caesiocinerea</i>	L	
<i>Barbula convoluta</i>	M	
<i>Brachythecium rutabulum</i>	M	
<i>Bryoria capillaris</i>	H	
<i>Bryoria fuscescens</i>	M	
<i>Bryum argenteum</i>	L	
<i>Buellia punctata</i>	L-M	
<i>Caloplaca cerina</i>	M	
<i>Caloplaca flavorubescens</i>	H	
<i>Caloplaca holocarpa</i>	M	
<i>Candelaria concolor</i>	M-H	
<i>Candelariella vitellina</i>	M	
<i>Candelariella xanthostigma</i>	M	
<i>Ceratodon purpureus</i>	L	
<i>Cetraria pinastri</i>	M	
<i>Cladonia chlorophaea</i>	M	
<i>Cladonia coniocraea</i>	M	
<i>Cladonia fimbriata</i>	M-H	
<i>Cladonia gracilis</i>	L-M	
<i>Collema tenax</i>	M	
<i>Encalypta procera</i>	H	
<i>Encalypta vulgaris</i>	H	
<i>Funaria hygrometrica</i>	L	
<i>Grimmia anodon</i>	M	
<i>Hyperphyscia adglutinata</i>	M	
<i>Hypnum cupressiforme</i>	M	
<i>Hypogymnia physodes</i>	L-M	
<i>Hypogymnia tubulosa</i>	H	
<i>Jaffeuliobryum raui</i>	M	
<i>Lecanora chlarotera</i>	M	
<i>Lecanora dispersa</i>	L	
<i>Lecanora hageni</i>	L	
<i>Lecanora muralis</i>	M	
<i>Lecanora saligna</i>	M	
<i>Lecidea atrobrunnea</i>	L	
<i>Orthotrichum pumilum</i>	H	
<i>Parmelia caperata</i>	M	
<i>Parmelia subaurifera</i>	H	
<i>Parmelia subolivacea</i>		L
<i>Parmelia sulcata</i>	M-H	M-H
<i>Phaeophyscia nigricans</i>	L-M	
<i>Physcia adscendens</i>	M	
<i>Physcia aipolia</i>	M	

<i>Physcia aipolia</i>	M	
<i>Physcia caesia</i>	M	
<i>Physcia millegrana</i>	M	
Table 10. Continued		
Species	SO ₂ Sensitivity	Ozone Sensitivity
<i>Physcia stellaris</i>	L-M	
<i>Physconia detersa</i>	M	
<i>Pohlia cruda</i>	L	
<i>Rhizoplaca melanophthalma</i>	H	
<i>Schistidium strictum</i>	M	
<i>Tortula ruralis</i>	M	
<i>Usnea hirta</i>	M	
<i>Usnea subfloridana</i>	M	
<i>Xanthoria elegans</i>	M	
<i>Xanthoria fallax</i>	M	
<i>Xanthoria polycarpa</i>	M	L

E. RESEARCH AND MONITORING NEEDS

Resource managers at THRO have insufficient data for predicting potential air pollution impacts on specific resources. For example, the sensitivity of native plant species to elevated ambient S compounds is poorly quantified. One can stand at certain locations on the park boundary and smell H₂S (D. Peterson, personal observation), which suggests that the gas is present in reasonably high concentrations; however, there is insufficient information on visible symptoms or physiological impairment of vegetation or effects on wildlife to determine if there are adverse effects. Numerous studies conducted on the effect of pollutants on park vegetation provide valuable baseline values for future comparison.

The park should establish strong public/private partnerships with the other federal and state agencies and other institutions to ensure that external threats are minimized and the interests of both the park and its neighbors are equitably met.

1. Deposition and Gases

Atmospheric concentrations of pollutants, especially S, need to be better quantified at THRO. A sulfation-plate study in 1987 found potentially elevated S deposition levels in the North Unit of the park, however the study was limited by an insufficient number of samples (Bilderback 1987). An extension of this study would be very useful in determining S distribution patterns. The possibility of utilizing portable ambient SO₂ and H₂S monitors in conjunction with the sulfation plates should be investigated. At the present time, the accuracy of such equipment is not sufficient to detect concentrations in the ppb range. However, if improvements in SO₂ and H₂S detection technology are made, it may become feasible to complete an intensive investigation of ambient levels in and

around the park. The South Unit should also be included in this study. A qualified statistician should be consulted before sampling begins in order to determine the most effective sampling methodology. Statistical rigor is needed not only to lend credibility to the study results but also to facilitate spatial analysis.

Monitoring data collected at the North Unit provide important information to support ongoing long-term environmental monitoring. Thus, it is critical to continue monitoring atmospheric concentrations at the North Unit. The South Unit has historically experienced lower atmospheric concentrations and deposition rates than the North Unit, but potential economic development in the vicinity could degrade air quality, and the park needs to be prepared to reinitiate monitoring. Data from the special purpose monitoring site established near the South Unit attests to the importance of monitoring small emitters (oil and gas wells) that are very near the park and can heavily impact the air quality in a small area. Periodic monitoring adjacent to local sources should be considered to document the potential effect of non-PSD sources on air quality in the park.

A better spatial characterization of ozone distribution at THRO would be useful, although levels are currently below those believed to adversely affect sensitive plant species. The ozone analyzer at the North Unit should continue to be operated in order to document any future changes. In addition, a network of passive ozone samplers would be useful to compare ozone measurements from different locations in the park. Three samplers in the North Unit, three in the South Unit and one in the Elkhorn Unit should be sufficient to spatially characterize the ozone distribution, with weekly samples collected for two months during the summer. Two years of monitoring should be sufficient to establish spatial patterns and a reference point in time.

One of the samplers could be colocated with the existing ozone analyzer at the North Unit to facilitate comparisons and as a check on the accuracy of the samplers. The two other samplers in the North Unit could be situated along the Little Missouri River. Placement near the river assures good air flow around the sampler. For the same reason, samplers in the Elkhorn and South Units could also be placed near the river. Samplers should be situated where they are reasonably accessible but not within 50 meters of a road or trail where they may be subject to excessive dust or vandalism.

2. Aquatics

We do not recommend any additional research or monitoring efforts with respect to aquatic effects of air pollutants in this park. Atmospheric deposition of acidic compounds and nitrogen are low in the park and are not expected to change dramatically in the near future. More importantly, the aquatic resources in the park are not sensitive to air quality degradation.

3. Terrestrial

It is difficult to establish a monitoring system for detecting air pollutant effects on plants of THRO because there are (1) few known visible symptoms of air pollutant effects on plants in the field in the northern Great Plains region, and (2) few data on pollution effects in plant species found in THRO. We must therefore rely on data published on other species and from experimental studies.

Currently, the threats to THRO terrestrial resources from SO₂ and H₂S are sufficiently urgent to monitor sensitive species. Very little information on the sensitivity of THRO plant species to H₂S is available. Surveys of plants adjacent to oil wells can be conducted to determine any potential foliar impacts caused by H₂S. Plants with potential symptoms can then be compared to plants within park boundaries. Threats from ozone are less urgent and monitoring ozone-sensitive species is not recommended at this time. However, if ozone concentrations increase in the future, monitoring should be considered. Three levels of monitoring associated with increasing amounts of effort and expense are detailed in Appendix A. It is recommended that quaking aspen be used as a sensitive receptor for both ozone and SO₂ at THRO. We recommend placing plots at four locations in THRO: two plots in the North Unit and two at the South Unit. Colocation of these plots with the electronic ozone analyzer and passive ozone samplers should be done when possible. Monitoring should follow the methodology developed by Forest Service and National Park Service scientists for evaluating pollutant injury (Stolte and Miller 1991, Stolte et al. 1992).

If lichens are included in a future monitoring effort, they should be monitored at locations adjacent to the tree plots. The epiphytic lichen *Parmelia sulcata* is a species that is recommended for further monitoring. Not only is it one of the most common species but it was found to contain relatively high levels of a large number of elements which indicates that it may be more sensitive to atmospheric inputs than other lichen species (Gough et al. 1985). Another recommended species for monitoring is *Orthotrichum pumilum*, which grows on the trunks of green ash trees (Bilderback 1987). This species has been found to be sensitive to SO₂ and is common in the park. Species that could also be investigated further as indicators include *Grimmia anodon*, *Jaffeuliobryum raii*, *Schistidium strictum*, *Hypnum cupressiforme*, *Tortula ruralis*, and *Brachythecium rutabulum*. These species are found on the large sandstone boulders in the park and therefore are well exposed to atmospheric inputs and are easily photographed and documented. When these species were surveyed in 1986 and 1987, none of them exhibited decreased abundance or injury (Bilderback 1987).

Herbaceous plants may also be used in future monitoring efforts. Some of the S-sensitive vascular plant species of THRO for which there is baseline information include western wheatgrass, and skunkbush sumac. Extensive chemical analyses are already available providing a valuable baseline with which to compare future analyses. Resurveys of lichens done after significant new pollution sources begin operating in the area should compare their results with these to determine what effects the new sources may be having on the lichen communities of THRO. Again, monitoring

should be done at locations adjacent to the tree plots wherever possible.

A study was completed by the USGS on the baseline elemental-composition of selected plants and soils in THRO (Gough et al. 1985). It has been over 10 years since the baseline study data was gathered. It is recommended that the park pursue funding to sample the same species again, particularly for S isotopes, to look for changes. A literature search should also be conducted to assess new knowledge that could be applied to this issue.

4. Visibility Recommendations

Energy development adjacent to the park may cause visibility impairment at THRO. Therefore, visibility monitoring (particle and optical) should be conducted at the park. The monitoring data could be used to assess potential impacts local energy development may have on visibility at the park.